

Taste Intensity, Pleasantness and Quality of Aspartame, Sugars, and Their Mixtures

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Abstract

Panelists evaluated both unmixed aqueous solutions of aspartame, and of three sugars (glucose, fructose, sucrose) at different levels, as well as aspartame-sugar mixtures (by the method of magnitude estimation) for each stimulus. Panelists evaluated sweetness, pleasantness, and overall qualitative dissimilarity to sucrose solutions. Each unmixed sweetener produced sweetness functions conforming to power equations. Mixture sweetness of aspartame with all three sugars could be predicted from a linear combination of component sweetnesses. Pleasantness was approximately an inverted U or L shaped function of sweetness. Dissimilarity to sucrose "flavor" was maximal for mixtures which comprised substantial amounts of aspartame relative to the sugar.

Résumé

On a fait évaluer pour chacun des stimulus par des experts en dégustation des solutions aqueuses d'aspartame, de glucose, de fructose et de sucrose à différentes concentrations et aussi des mélanges aspartame-sucrose (par la méthode de l'ordre des grandeurs). Les experts ont évalué la douceur, l'agrément et la dissimilarité qualitative générale par rapport à des solutions de sucrose. Chacun des édulcorants purs ont donné des fonctions pour la douceur en conformité aux équations de puissance. On a pu prédire par la combinaison linéaire des douceurs des composants, la douceur d'un mélange d'aspartame avec les trois sucres. L'agrément a été en gros une fonction de la douceur en forme de L ou de U inversé. La dissimilarité au goût du sucrose a atteint un maximum avec les mélanges contenant des quantités substantielles d'aspartame par rapport à la quantité de sucre.

Introduction

Recent studies (Cloninger and Baldwin, 1970) have reported that aspartame (aspartyl phenylalanine methyl ester) is a highly acceptable, low calorie sweetener, with little or no aftertaste. There is little information about aspartame with regard to: a) its relative sweetness over a large range of concentrations; b) its sweetness contribution in mixtures with sugars; c) its acceptability to panelists, in both unmixed and mixed form (with sugars); and d) its qualitative dissimilarity to sucrose. The present study investigates all of the above, using the method of magnitude estimation (Moskowitz, 1974b), which allows the experimenter to develop a ratio scale of sensory magnitude, or a ratio scale of taste acceptability, using panelists in the potential consumer population.

Recently, evidence has accumulated which suggests that the sweetness of mixtures of sugars can be predicted from knowledge about the sweetening powers of their components. Early studies by the Canadian chemist A. T. Cameron (1947) reported a tedious but reliable method for predicting the total sweetening power of a mixture of two (or more) sweeteners. Each sweetener (A,B) was converted to an equivalent sweetness of a reference substance (C).

For a mixture comprising concentration X of sweetener A and concentration Y of sweetener B, Cameron first determined the concentration of sweetener C equivalent in sweetness to X alone (call this X'), and the concentration of sweetener C equivalent to sweetness to Y alone (call this Y'). Then, Cameron determined the concentration of sweetener C (M) equivalent in sweetness to the empirical mixture of X and Y. Additivity was inferred when $X' + Y' = M$. Additivity often was observed when the components of a mixture were sugars, and when the reference sweetener C was glucose (dextrose). Additivity did not occur when: a) the reference sweetener C was either fructose or sucrose (primarily because these sweeteners exhibit non-linear sweetness-concentration curves, even in log-log coordinates); or b) the sweeteners mixed were amino acids + sugar.

With the advent of direct magnitude estimation (Stevens, 1953) psychophysicists and food scientists were afforded a direct numerical measurement of sweetness, exhibiting ratio-scale properties. Taste intensities could be added together, subtracted, and multiplied by a scalar quantity.

According to Moskowitz (1973), at least two potentially different models of additivity may govern taste:

Model I states that the taste system behaves in the manner proposed by Cameron. That is, the taste system responds to a mixture as if it were a higher concentration of a single taste substance. Computationally, Model I can be expressed by the simple equation:

$$\text{Sweetness (A,B)} = k_a (C_a + C'_a \sim C_b)^{N_a}$$

The expression in parentheses represents the concentration of sweetener A, added to the concentration of sweetener B (C'_b), with the latter concentration converted to a concentration of A which matches B. That is, the taste system sums equivalents of sweetness (equivalent in terms of A here, but just as easily in terms of another sweetener), and then transforms the total to the appropriate perceived sweetness, by means of a power function (which fits many sweetness-concentration relations (Meiselman, 1972)).

Model II states that the taste system adds together the two perceived sweetnesses of the components:

$$\text{Sweetness (A,B)} = \text{Sweetness (A)} + \text{Sweetness (B)} = K_a (C_a)^{N_a} + K_b (C_b)^{N_b}$$

Both models need corrective multiplicative constants, since the perceived sweetness of a component added to itself for model II would be $k_a (C_a)^{N_a} + k_a (C_a)^{N_a}$, which add

to $2k_a (C_a)^{Na}$. This does not equal $k_a (2C_a)^{Na}$ for the power function exponents greater or less than 1.0.

Recent reports of sweetener mixtures suggesting synergistic effects (viz. that the sweetness of the mixture exceeds the predicted sweetness, by either model) have been published by several groups (e.g., Moskowitz, 1973, 1974; Stone & Oliver, 1966; Stone, Oliver & Kloehn, 1969; Yamaguchi, 1970). More complex effects occur in mixture studies in which pairs of artificial sweeteners are combined (e.g., Na and Ca cyclamate, Na cyclamate and Na saccharin, Na and Ca saccharin, respectively; Moskowitz & Klarman, 1975a). These complex effects do not permit modeling of the simple form suggested above, since for some sweetener mixtures a pair of components may produce an overall taste intensity less than the higher of the two (viz. suppression occurs in these mixtures).

Evaluation Of Hedonic Tone

Pleasantness and unpleasantness often are immediate reactions to sweet (as well as salty, sour and bitter) substances. For taste, Engel's classic studies (1928) suggested that sweetness (e.g., of sucrose) in aqueous solution is probably most acceptable at a sucrose level around 9-10%. Later studies using magnitude estimation and category scaling for simple sweeteners confirmed this (Kocher & Fisher, 1969; Moskowitz, 1971, Moskowitz & Klarman, 1975b). There exists an inverted U or L shaped function for perceived pleasantness of aqueous sugar and glucose solutions vs. concentration, and the form of this function is surprisingly robust, reoccurring in normally sweetened foodstuffs (Moskowitz *et al.*, 1974), and for populations other than Westerners (Moskowitz *et al.*, 1977).

For artificial sweeteners the bitterness associated with cyclamate and saccharin contributes another flavor note, this time an unpleasant one, and it is the panelist's task to decide upon a hedonic rating when confronted with a stimulus that is simultaneously pleasant and unpleasant. Moskowitz & Klarman (1975b) suggested that for mixtures of cyclamate and saccharin, it was virtually impossible to predict overall pleasantness/unpleasantness from knowledge of the molar concentrations alone. Rather, predictions of pleasantness were made by first determining the sweetness or bitterness rating of the mixture, and then predicting overall pleasantness/unpleasantness from a linear combination of the two intensity ratings. For aspartame and sugar there should be little bitterness to complicate the observer's estimate of overall liking/disliking, and thus one might expect to see the typical inverted U or L shaped function reappear.

Methods

Stimuli—In three experiments, three sets of stimuli were prepared. Each stimulus set comprised the following concentrations: 6 levels of aspartame, 6 levels of one of three sugars (either sucrose, glucose, or fructose, respectively) and, in addition, all 36 possible mixtures (total = 48 stimuli). A concentration of X% aspartame and Y% sucrose comprised X grams of aspartame, Y grams of the sucrose, both in 100 ml total volume of solution. (See Table 1)

The sugar sweeteners were reagent grade material. Aspartame was procured from Searle Biochemicals, Inc. All solutions were prepared in advance, stored in small plastic

bottles, with airtight caps, and frozen until the day before use to permit stable storage of a large number of samples. The solutions were brought up to room temperature, and served from the same plastic bottles (which had been thoroughly cleaned before use to remove any extraneous tastes or smells which might have contaminated the bottles).

Table 1. Concentrations of sweeteners and mixtures^a.

Sucrose	1%	2%	4%	8%	16%	32%
Glucose	1%	2%	4%	8%	16%	32%
Fructose	1%	2%	4%	8%	16%	32%
Aspartame	.01%	.02%	.04%	.08%	.16%	.32%

^aFor each combination (sugar x aspartame) all 36 mixtures were also evaluated.

Panelists—The panelists were 14 women, who had had previous experience in both olfactory and taste psychophysical studies. All panelists were screened for ability to taste, and none showed any gross abnormalities. The panelists participated in the experiment for six days. During each of days one and two the panelist evaluated one set of solutions (viz. one set of stimuli, either sucrose, glucose or fructose and aspartame) three times, during days three and four they evaluated another set three times, and during the fifth and sixth days they evaluated still another set three times. Thus, the data from the 14 panelists actually reflected 42 replicate judgments per stimulus.

Experimental design and instructions—In a 2 hr session, each panelist evaluated 48 stimuli (6 levels of each mixture component, 36 mixtures). The panelists were instructed to evaluate each stimulus for three separate attributes, using the method of magnitude estimation (Moskowitz, 1974; Moskowitz & Sidel, 1971). These were: a) sweetness; b) pleasantness/unpleasantness; and c) qualitative dissimilarity to a standard sugar solution (17.2% sucrose in water). For the evaluation of sweetness, panelists were instructed to rate increasing amounts of sweetness, using only positive numbers, with 0 representing the fact that they could not perceive the sweetness, and higher numbers reflecting increasing degrees of sweetness. For pleasantness/unpleasantness, negative numbers were to reflect increasing degrees amount of disliking, 0 was to represent neither liking nor disliking (neutrality), and positive numbers were to represent increasing amounts of liking. In order to indicate the perceived degree of qualitative dissimilarity between the test solutions and the stimulus solutions, a 0 was to reflect qualitative identity (viz. that the two solutions did not differ in sucrose-sweet quality, although they might differ in perceived sweetness) and increasing numbers were to reflect increasing amounts of qualitative dissimilarity. At the end of the experiment, panelists also rated on their own scale the value corresponding to "moderately" sweet, moderately liked, and moderate amount of dissimilarity. An initial normalization of each replicate for each panelist was done by dividing all of the panelist's sweetness judgments for the stimuli (in that replicate) by moderately sweet and post multiplying by 30. Similar normalization was done for unpleasantness/pleasantness (viz. initial division by moderately pleasant and then post multiplication by 30 to maintain ratios, yet avoid small decimals), and a similar normalization was done for dissimilarity as well. The normalization reduced

the overall variance in the data, but did not change the ratios of the judgments for a given panelist.

The three replicates for each panelist for each stimulus were then averaged (arithmetically) to obtain one single estimate of the sweetness, the unpleasantness/pleasantness and the overall dissimilarity from ideal sugar solution. These were then submitted to the PSYCHMB program (Klarman and Moskowitz, unpublished), which computed the following:

- Summary statistics (means, median, standard deviation, interquartile range).
- Psychophysical functions (power functions $S = kC^n$) relating concentration (C) to sensory estimate (S), and goodness of fit statistics (Pearson R and F ratio for linearity of regression).

Results

Unmixed sweetness—Figure 1 presents the simple dose-response functions for the four sweeteners considered here: sucrose, glucose, fructose and aspartame. The median of 14 judgments (after individual replicates were averaged for each observer) was used as a measure of central tendency. In the present experiment, the lowest concentrations of sweeteners were often not detected, and were given a magnitude estimate of 0. At the higher concentrations, the non-zero magnitude estimates tend to fall along a straight line in log-log coordinates, with the slope of the line provided by Table 2 (for those concentrations whose median value was not zero). As expected on the basis of previous studies

Table 2. Sweetness power functions for unmixed sweeteners (C = % by weight in aqueous solution).

Aspartame (all experiments combined)	
Log sweetness = 2.09 + 1.17 (log C): Sweetness = 123.0 $C^{1.17}$	
Standard error of estimate = 0.17	
Correlation = 0.95	
F (1,12) = 111.59 (P < .001)	
Glucose	
Log sweetness = -2.03 + 2.42 (log C): Sweetness = .0093 $C^{2.42}$	
Sucrose	
Log sweetness = -1.05 + 1.79 (log C): Sweetness = .089 $C^{1.79}$	
Fructose	
Log sweetness = -0.50 + 1.49 (log C): Sweetness = .32 $C^{1.49}$	

using the simple sip-expectorate procedure, the exponent of the power function turned out to exceed 1.0 for the sugars, which means that the observer expands the ratio of physical concentrations of sugar into larger ratios of perceived sweetness. Such expansion (viz. sweetness growing according to an accelerating function) also occurs for aspartame as well (exponent = 1.17) which implies that this artificial sweetener produces accelerating sweetness functions. In contrast, previous studies which have assessed the sweetening power of saccharin and cyclamate (Moskowitz, 1970; Moskowitz & Klarman, 1975a) have shown that artificial sweeteners conform to decelerating functions.

Figure 1 also presents the relation between concentration and the perceived dissimilarity (in quality) between the sweeteners and 17.2% w/v of sucrose. The coordinates are semi-logarithmic. Aspartame becomes increasingly similar to sucrose as its sweetness approaches that of 17.2% sucrose. The three experiments produced superimposable dissimilarity functions, which appear as V's. The sugars

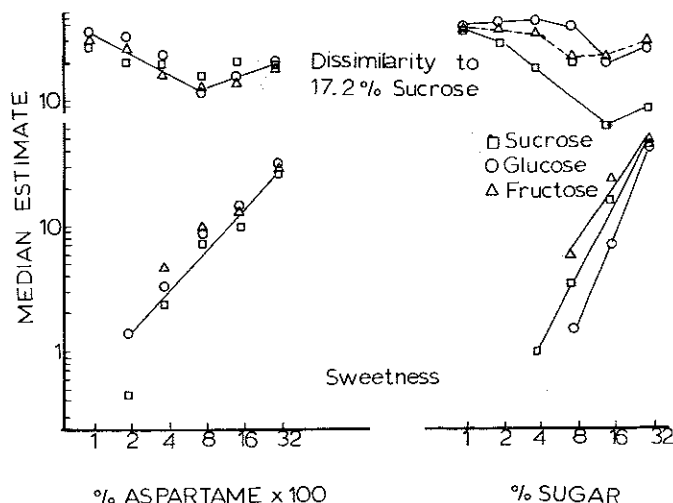


Fig. 1. Relation between concentration of sweeteners (percent weight) and both perceived sweetness, and perceived dissimilarity to an aqueous solution of 17.2% sucrose. The coordinates are log-log, in which power functions show up as straight lines. Data for aspartame from the three experiments are superimposed.

also become increasingly similar (or least dissimilar) in quality to 17.2% sucrose. In this study, observers were cautioned to disregard taste intensity but may not have been able to when making their estimates. Nonetheless, it appears that the results conform to a lawful curve, which has intuitive appeal.

According to previous findings (Moskowitz, 1971; Moskowitz *et al.*, 1974) the relation between sweetness (or sugar concentration) and perceived pleasantness (liking) of aqueous solutions or of normally sweetened foods is curvilinear, and may be approximated by a parabolic function. Figure 2 shows the relation between perceived pleasantness and concentration.

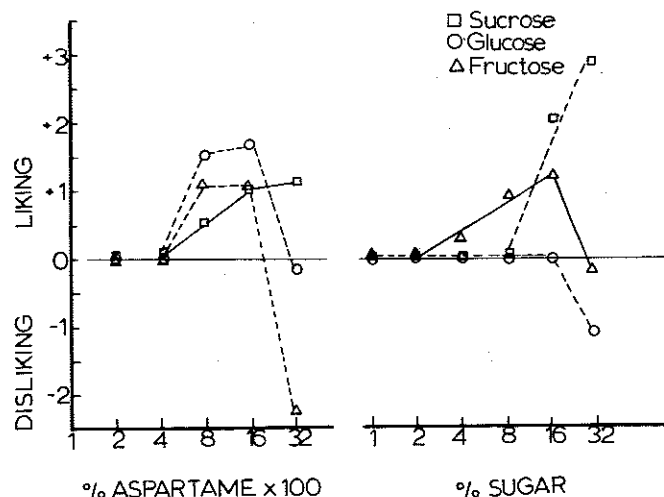


Fig. 2. Relation between percent concentration of sweeteners (in logarithmic spacing) and mean hedonic ratings, on a magnitude estimation scale (in linear spacing). 0 reflects neutrality, positive numbers reflect liking, and negative numbers reflect disliking. The values for hedonics have been multiplied by 0.1, so that a value of 1 actually reflects a value of 10. Data for aspartame from the three experiments are superimposed.

In this experiment, aspartame obtained in maximum pleasantness (liking rating) at a concentration between 0.08% and 0.16% w/v, equivalent to the sweetness provoked by 1.0 M glucose (approximately 18%). Thus, in the hedonic evaluation of aspartame, the function resembles that of glucose, with an intermediate maximum point (around 0.16%). This provokes a sweetness of approximately 15, which is as sweet as 16-18% glucose (~M) (that level is the most pleasing level of glucose as well; Moskowitz, 1971; Moskowitz & Klarman, 1975b.) In contrast, the evaluation of sugars (Figure 2) produced an increasing function for sucrose, a neutral one for glucose (which begins to descend towards disliking at 16% w/v, almost 1.0 M) and an inverted U or L shaped function for fructose. The breakpoint for glucose is maintained at approximately 1.0 M, with the exception that the breakpoint is a maximum pleasantness, which in terms of the median ratings never departed from neutrality.

Psychophysical vs. psychometric functions for intensity—Quite often it is desirable to describe mixture sweetness in terms of a combination rule, which concatenates concentrations of the two components. Cameron (1947), Moskowitz (1973, 1974a), Moskowitz & Klarman (1975a), and Stone & Oliver (1966) attempted to do this for sugars and for artificial sweeteners. Yamaguchi (1970) attempted the same task, this time with a complicated equation which allowed for synergistic effects. The present study takes a different approach, and one based upon previous observations with attempts to predict mixture pleasantness from concentrations of components (Moskowitz & Klarman, 1975a). The approach is two-fold:

a) For each unmixed sweetener evaluated, determine its unique psychophysical function. This function is traditionally a power function when magnitude estimation is used (Stevens & Galanter, 1957), although a host of other functions can also be used to describe the data.

b) For each mixture, determine the relation between perceived sweetness of the mixture, and the component sweetnesses of the concentrations which the mixture comprises. This can often be described by a simple linear model, of the form:

$$S_{\text{mix}} = k_1(S_a) + k_2(S_b) + k_3$$

(The additive constant, k_3 , may be deleted if desired, since 0 sweetness levels of both components would normally be an overall 0 level of mixture sweetness.)

The final step in the procedure is to substitute component power functions for sweetness values (S_a, S_b) in the mixture equation. The weights for sweetness (k_1, k_2) obtained by the mixture analysis allow the experimenter to assign the relative contributions of the components to overall sweetness. These weights (k_1, k_2) are obtained from predicting one subjective response (mixture sweetness) from a combination of other subjective responses (component sweetness).

Table 3 shows the parameters of the equation for additivity, the correlation coefficient for goodness-of-fit, and the F ratios for linearity of regression.

In addition, Table 3 shows the entire display of a psychophysical function which predicts mixtures on the basis of a) initial determination of sweetness functions, and b) use of those sweetness functions in a mixture equation.

Table 3. Mixture equations for sweetness.

EXP. I: Glucose (G) + Aspartame (A)	
Sweetness = $0.63(S_G) + 0.90(S_A) + 3.97$	
(R = 0.94, F = 161.11, df = 2,45)	
Sweetness = $.0058(C_G)^{2.42} + 110.7(C_A)^{1.17} + 3.97$	
EXP. II: Sucrose (S) + Aspartame (A)	
Sweetness = $0.79(S_S) + 0.86(S_A) + 3.44$	
(R = 0.95, F = 223.3, df = 2,45)	
Sweetness = $0.70(C_S)^{1.79} + 105.78(C_A)^{1.17} + 3.44$	
EXP. III: Fructose (F) + Aspartame (A)	
Sweetness = $0.74(S_F) + 0.69(S_A) + 5.32$	
(R = 0.93, F = 152.97, df = 2,45)	
Sweetness = $.24(C_F)^{1.49} + 84.87(C_A)^{1.17} + 5.32$	

S = Sweetness
C = % concentration (w/v)
G = Glucose

S = Sucrose
F = Fructose
A = Aspartame

In all three experiments, the predictability of mixture sweetness from component sweetness is high, and, in two experiments, aspartame sweetness is given approximately the same weight (viz. coefficient) as the sugar sweetness. This means that the taste system adds together the component sweetnesses. Since the coefficients are less than 1.0 each, there is incomplete additivity of sweetness. The high correlation coefficients and the relatively low additive constant (ca. 3-5) mean that the additive model fairly well describes the data and that the additive constant may be non-zero because of error in the sensory ratings.

Hedonics—In a previous study (Moskowitz & Klarman, 1975b), attempts were made to relate mixture pleasantness for combinations of pairs of artificial sweeteners to the component pleasantnesses of each one evaluated separately. This approach did not work because a) the mixtures developed strong bitter tastes which exceeded the bitteresses of the components (and so an entirely new taste percept developed), b) mixture pleasantness is related to mixture sweetness, and pleasantness itself is a curvilinear function of sweetness. That study concluded that one would have to determine the taste of a mixture and then predict pleasantness from knowledge of the generalized taste-pleasantness relation (which is parabolic). It is difficult at present to derive a simple additive model for summation of pleasantnesses of mixture components for the data as well.

Contour Maps—Quite often it is of interest to "scan" the entire range of pairwise mixtures at a single glance, to determine the general trends of the data (i.e., does the data show specific "humps" or "depressions" in the middle which were not expected, is it monotonic with concentration in both directions—as each component increases, etc.).

Figure 3 shows three sets of representative contour maps developed by a procedure which attempts to fit a smooth surface (or grid) to the empirical data points. The figure was drawn by the CALCOMP Inc. system, from knowledge of the concentrations of each component and either the rated sweetness, the rated pleasantness, or rated dissimilarity. Intermediate concentrations and estimated sweetness, pleasantness or dissimilarity levels, respectively, were derived by smoothing procedures, which took values from adjacent concentrations of known sensory levels.

The three dimensional surfaces for sweetnesses show a steady rise in perceived sweetness in both directions, as the

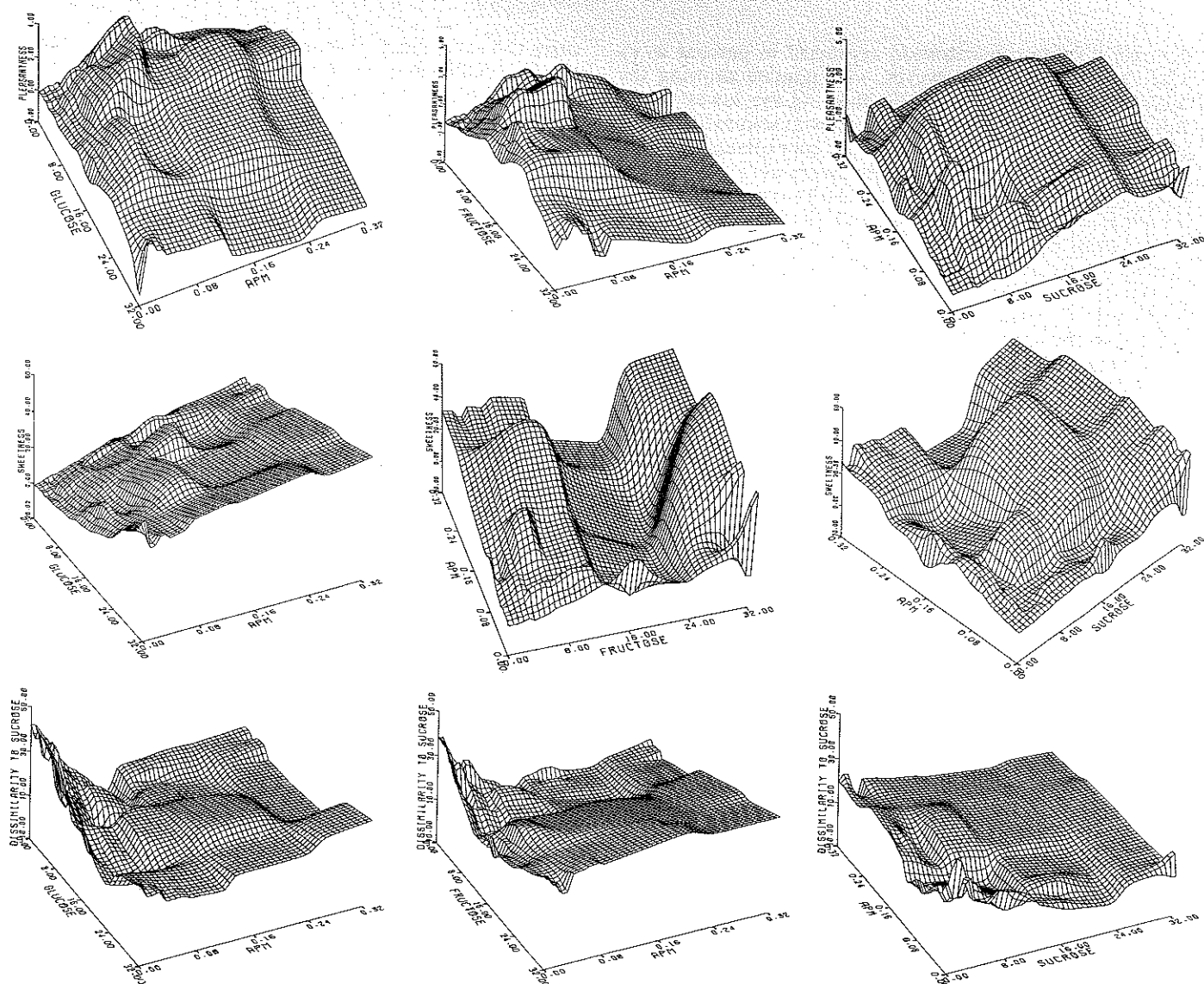


Fig. 3. Contour maps, relating sweetness, pleasantness (liking/disliking) and dissimilarity to 17.2% sucrose to the component concentrations of the mixtures. A CALCOMP map was drawn in three dimensional perspective, based upon the empirical values for concentrations of the components, subjective ratings, and an internal, computer-generated, set of intermediate points between the concentrations. The surface is an estimated one, based upon "smoothing" procedures in which intermediate points are computed from the existing data by mathematical routines.

concentrations of the components increases. This gradual rise is interrupted, at some concentrations (e.g., at the 0.32% w/v of aspartame and between 16 and 24% w/v sucrose). The reason for this dip, as well as the dip for 16-24% w/v fructose + all levels of aspartame, is not clear. It may reflect either random error in the data (as might be the case for the mixture of aspartame + sucrose) or a systematic suppression, which is sensitive to concentration (e.g., fructose + aspartame).

Each of the pleasantness contours appears to be shaped like a surface with one major (or perhaps two adjacent) peaks. The peaks occur at different positions on the map, depending upon concentration and type of sweetener. The peaks may either be broad or narrow, depending upon the combination of sweeteners, and the particular perspective of the computer generated plot.

The contour describing the dissimilarity to sucrose (at 17.2% w/v) shows a broad plateau over most of the region, punctuated by regions where perceived dissimilarity is noticeably higher. These regions tend to occur in the mid-ranges of concentrations of the components.

Discussion

The present results bear most strongly upon two issues in the assessment of sweetness intensity of components and their mixtures. The perceived sweetness of the three sugars tested here (glucose, fructose, sucrose) grows as power functions of concentration, with exponents exceeding 1.0. The exponents are somewhat higher than those reported in other studies (cf. Meiselman, 1972 for a list of power function exponents for sweetness). This means that the sweet taste of sugar is an accelerating function of con-

centration (with concentration expressed in percent w/v). The exponents differ, however, with glucose showing the highest exponent, and fructose showing the lowest exponent. This implies that the sugars grow at somewhat different rates in perceived sweetness with concentration. In addition, the functions for the three sweeteners are offset so that at the same percentage (or solids) concentration the sweetnesses of the sugars differ, with the ratio of sweetness provided by the ratio of magnitude estimates at that concentration. In contrast to sugars, the perceived sweetness of aspartame grows at a slower rate, approximately linearly with concentration. This growth rate stands in marked contrast to the lower exponents usually found for artificial sweeteners, such as saccharin and cyclamate (Moskowitz, 1970; Stevens, 1969).

The lower concentrations of the sweetness functions for sugar were often-times 0, suggesting that panelists could not detect any taste for these sugars. That is encouraging, since it suggests that there is little if any aftertaste imparted by the sugars, by aspartame, or by aspartame-sugar mixtures preceding these low concentrations. In contrast, saccharin and cyclamate produce quite noticeable bitter aftertastes.

The mixture rules developed here also present a refinement over previous suggested approaches. Cameron (1947) could never use psychological units of sweetness in his equal-sweetness matches, and was always forced to use measures of concentration. The method of magnitude estimation allows the experimenter to derive combination rules for psychological entities (viz. perceived sweetnesses), and psychophysical rules (viz. the relation between perceived sweetness of a component in a mixture and the concentration in physical measure). In addition, previous attempts by Moskowitz (1973) to model the sweetness of mixtures of pairs of sugars (glucose-fructose) and pairs comprising a sugar (glucose) and an artificial sweetener (cyclamate, saccharin) showed severe problems, since quite often the sweetness-concentration functions for cyclamate and saccharin were curvilinearly related. The present approach allows for the composition of two sets of functions (combination rules, psychophysical functions), each of which can be estimated separately.

It is interesting to note that in two mixtures, the components do in fact contribute approximately equally, as shown in Table 3. Ideally, were the taste system to respond to the sweetness of each sugar and aspartame, it should assign equal weights of 1.0 to the sensory information imparted by both. It may or may not. Whether unequal weights represent: a) overlapping receptor sites (in which

cases the asymmetry of overlap would reflect an asymmetry in coefficients), or b) possible sweetener additivity coupled with mutual suppression is unknown and merits further investigation.

Conclusions

The present results suggest the following:

1. Within a single session, panelists can scale the perceived sweetnesses of several concentrations of two sweeteners (one is aspartame, the other is a sweet sugar, such as glucose, or fructose), as well as a set of mixtures.
2. Panelists can attend to three attributes when making their judgments.
3. Except for mixtures of aspartame + fructose, the other mixtures show simple additivity of sweetness at most concentrations.
4. There tends to be a parabolic relation between sweetness and pleasantness, but the precise form of the function is distorted, quite possibly because of the few concentrations of sugars that were tested in unmixed form.

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